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GPS & GALILEO. FRIENDLY FOES?

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Contents

Illustrations

Tables

Page

Preface

The European Union is developing Galileo, its own global positioning and navigation satellite system, scheduled to be operational by 2010. The European Union states that Galileo will provide greater precision to all users than is currently available from the United States' Global Positioning System, improved coverage of satellite signals at higher latitudes, and will be guaranteed to be available in times of war or political disagreement. In light of the enormous importance of the Global Positioning System to the United States and hundreds of millions of users worldwide, the prospect of a second, competing and potentially interfering global satellite navigation system could have serious military, foreign policy, and industrial implications. The emergence of the Galileo system will affect the transatlantic alliance, the North Atlantic Treaty Organization, the US dominance in defense and security of Europe, and there are serious commercial and industrial concerns as well. The US government would benefit from a heightened awareness of the risks and opportunities for the United States surrounding the Galileo program.

Abstract

The European Union's global navigation satellite system, Galileo, poses concern for the United States' Global Positioning System. Areas of exploration include a brief history of satellite navigation and the Global Positioning System program, followed by an in-depth overview of the Galileo system, highlighting its multifaceted justification, expected economic benefits and revenue streams, and its four-year frequency battle with the Global Positioning System. Critical to this discussion is understanding Galileo as an expression of European sovereignty and the United States' corresponding reaction, the importance of the significant international interest in and cooperation with Galileo, and the strategic implications of China's evolving satellite navigation system. Five distinct actions by the United States government are necessary to protect its industrial, military, and national security interests: acknowledge the existing situation; ensure fair competition for satellite navigation hardware manufacturers; compel allied militaries to adopt GPS now; drive home the fact that, counter to European claims, the availability and precision of GPS will be on par with or better than Galileo; and secure China's cooperation in satellite navigation.

Chapter 1

Introduction

> *Competition has been shown to be useful up to a certain point and no further, but cooperation, which is the thing we must strive for today, begins where competition leaves off.*
>
> — Franklin D. Roosevelt (1882–1945), U.S. President

Introduction to the GPS and Galileo Programs

The United States (US) launched its original Global Positioning System (GPS) satellite in 1978, the first of a constellation of 24 satellites that has provided the global community with increasingly accurate positioning, navigation, and timing data at no cost for nearly three decades. Now the European Union (EU) has embarked on developing and launching Galileo, its autonomous global positioning and navigation satellite system, scheduled to be operational by 2010. Galileo's constellation of 30 satellites, each flying with the most precise atomic clocks ever launched into space, is intended to provide greater precision than GPS and improved coverage to its users at high latitudes than is currently available from GPS. In addition, the EU emphasizes that civilian control of Galileo and its commercial focus guarantee its availability even in times of war or political disagreement.

Overview of Major Galileo Issues

The Galileo program is a watershed in EU activity; it is the largest project ever organized on a European scale, and it will be the first public infrastructure owned by the European institutions. It is seen by many as a way of developing European cohesion while providing important economic benefits, such as creating over 100,000 EU jobs, as well as generating a positive revenue stream by charging fees for enhanced positioning and navigation services. In addition, Galileo can be seen as a political statement of European independence from the US, as Galileo furthers EU sovereignty and provides an alternative to US military and political hegemony in the area of global navigation. Galileo will assert Europe's independence by giving the EU countries guaranteed access to a critical service that currently is provided by the US; similar drives for operational autonomy led to the Airbus consortium of European airplane manufacturers and the Ariane space rocket program.

In light of the enormous importance of GPS to the US and hundreds of millions of users worldwide, all facets of a potentially competing, global satellite navigation system must be closely examined to uncover possible operational, industrial, military, and national security implications. In addition, China's heavy involvement in the Galileo project presents a national security dilemma for the US, as Galileo technologies shared by EU nations would certainly enhance China's military modernization and intelligence programs, not to mention China's own evolving satellite navigation system.

Chapter Preview

To properly introduce this topic, Chapter two documents the evolution of satellite navigation by first examining the GPS program, its augmentation systems and modernization plans, and then introduces Russia's Global Navigation Satellite System (GLONASS) and China's Compass

Navigation Satellite System. Chapter three is an in-depth focus on the Galileo program, its multifaceted justification, Galileo's expected economic benefits and revenue streams, and the four-year frequency battle with GPS. Chapter four examines Galileo as an expression of EU sovereignty, the corresponding US reaction, the importance of the significant international interest and cooperation with Galileo, and the strategic implications of China's Compass system. Finally, Chapter five presents five actions for the US government could undertake to protect its industrial, military, and national security interests: acknowledging the existing situation; ensuring fair competition for satellite navigation hardware manufacturers; compelling allied militaries to adopt GPS now; driving home the fact that, counter to European claims, the availability and precision of GPS will be on par with Galileo; and securing China's cooperation in satellite navigation.

Chapter 2

History of Satellite Navigation

Early Days of Navigation

Throughout time, people have developed a variety of ways to determine their position on earth and to navigate from one place to another. Early mariners relied on angular measurements to celestial bodies such as the sun and stars to calculate their location. The magnetic compass was invented around the year 1200, followed soon by the sextant which underwent refinement over the next several centuries. Marine chronometers, developed in the late 18th century, provided precise timing measurements that, when coupled with sextant sightings of planets and stars, signified the only reliable means of determining a ship's position in unfamiliar waters.[1] In the 1920s, several nations constructed radio beacons along their coastlines to aid sea navigation, but the military recognized that surface-based beacons suffered at least one strategic flaw – they were vulnerable to enemy attack. The space race provided a solution to this: placement of the beacons in earth-orbiting satellites. Following the 1957 launch of the Soviet Union's Sputnik 1, the world's first artificial satellite, a team of US scientists monitored Sputnik's radio transmissions. They discovered that, because of the Doppler Effect, the frequency of the signal being transmitted by Sputnik was higher as the satellite approached, and lower as it continued away from them. They realized, that since they knew their exact location on the globe, they could pinpoint where the satellite was along its orbit by measuring the Doppler distortion.

The first US satellite navigation system, Transit, was a constellation of five navigational satellites declared fully operational in 1964. The US Navy developed and deployed Transit to help guide their Polaris ballistic missile submarines and missiles, and the system provided a two-dimensional navigational fix approximately once per hour, with a rated accuracy of 200 meters.[2] During the next 10 years, the US experimented with several satellite navigation systems, but these were largely ineffective, as none provided dependable global coverage. In August 1974, the Deputy Secretary of Defense declared that NAVSTAR GPS (Navigation Satellite Timing and Ranging Global Positioning System), a program that combined the best elements of all existing radio navigation technologies, would be a tri-service program, with the Air Force serving as the program manager.[3]

Global Positioning System

The GPS constellation consists of at least 24 satellites, 21 of which perform the navigation mission and three are active spares. Their orbits are arranged so that five to eight satellites are always within line of sight from almost anywhere on Earth. The launching of GPS satellites began in 1978, and the program officially reached full operational capability in April 1995. As of February 2007, there were 30 actively broadcasting satellites in the GPS constellation.[4]

The ground portion of GPS synchronizes the atomic clocks on board the satellites into a common "GPS time" and tracks their flight paths. It consists of the master control station at Schriever AFB in Colorado Springs, five Air Force monitoring stations (Hawaii, Kwajalein Atoll, Ascension Island, Diego Garcia, and Colorado Springs) and three ground antennas located throughout the world (Ascension Island, Diego Garcia, and Kwajalein). Finally, a user's GPS receiver locates four or more of these satellites, calculates the distance to each, and uses these measurements to determine its location, speed, and time.[5]

GPS Services

Positioning, navigation, and timing technology is inherently dual-use, and GPS is no exception. “The precision, availability, and speed of its two service levels have made it essential to bankers, network administrators, hikers, pilots, drivers, infantry, and generals alike.”[6] The Standard Positioning Service (SPS) is available to all users on a continuous worldwide basis, is free of any direct user charge, and is broadcast on a single frequency. The more secure and survivable Precise Positioning Service (PPS) is encrypted, incorporates anti-spoofing measures, and broadcasts using two frequencies; the additional frequency provides an added degree of jamming resistance. Access to the PPS is restricted to US armed forces, US Federal agencies, and selected allied armed forces and governments equipped with classified PPS receivers and a current cryptographic key.[7] To prevent an enemy from accessing the PPS via a military receiver, the cryptographic key can be erased with the flick of a switch on the receiver;[8] in the event a keyed military receiver is recovered by an adversary, access to the PPS will be short-lived, as the crypto key must be updated regularly and frequently.

Selective Availability

“Selective availability was the intentional degradation of the GPS signal that made it less precise for civilian users and was initially intended to ensure that the US military and selected allies obtained greater benefit from GPS than anyone else.”[9] First and foremost, GPS was designed to provide US and allied military forces with a positioning and navigational advantage when engaged with other military forces, while still providing a reasonable positioning service to the civil community. In 1983, after Soviet interceptor aircraft shot down the civilian airliner KAL 007 in restricted Soviet airspace, killing all 269 people on board, President Reagan announced that GPS would be made available for civilian use once it was completed. During

that same year, the DOD announced that GPS would provide no better than 100m precision to civilian users, using Selective Availability (SA) to degrade the signal. The DOD, in accordance with the Federal Radionavigation Plan, first activated SA in March 1990, much to the dismay of the civil GPS user community.[10]

The 1990-1991 crisis in the Persian Gulf, the first major test of GPS in a combat situation, proved beyond a doubt its importance and utility, even though "the satellites available in 1991 provided…16.75 hours of three-dimensional GPS service daily."[11] "Some say that GPS revolutionized combat operations on the ground and in the air during Operation Desert Storm and was, as one Allied commander noted, one of two particular pieces of equipment that were potential war winners (the other was night-vision devices)."[12] However, the shortage of military GPS receiver units and the wide availability of commercial ones among coalition forces resulted in a decision to disable SA from August 1990 through 15 November 1991. This was ironic, as SA had been introduced specifically for these situations, allowing friendly troops to use the signal for accurate navigation, while at the same time denying it to the enemy. But since SA was also denying the same precision to thousands of friendly troops, turning it off presented a clear benefit. "Fortunately, Iraq did not possess a weapon system that depended on GPS for guidance."[13]

During the 1990s, SA presented a problem for US civilian agencies requiring accurate positioning data, such as the Federal Aviation Administration, the Coast Guard, and the Department of Transportation. However, citing security concerns, the US military repeatedly rejected requests from these agencies to turn off SA. This led to the development and operation of several Differential GPS (DGPS), systems that locate ground receivers at surveyed locations, determine the GPS signal error by comparing the received GPS positioning data to the known

location, and then broadcast this error measurement to user receivers. Depending on the amount of data being sent in the DGPS correction signal, correcting for these effects can reduce the error significantly; the best implementations offer accuracies of about 5 mm.[14]

To encourage greater civilian, commercial, and scientific use of GPS, President Bill Clinton's March 1996 Presidential Decision Directive (PDD) on GPS stated the US would turn off SA by 2006. Further, it promised the US would continue to provide basic GPS signals worldwide and free of user charges.[15]

GPS remained a military program, and the US Air Force continued to oversee its day-to-day operations. The US Air Force had provided this global service with superb results since its inception, and no other agency was prepared to manage or to fund GPS.[16] "The dilemma was that there was little real internal incentive for the US Air Force to optimize GPS services for civilian and commercial use. The Air Force objective was a satellite navigation system that met present and future military needs. Surprisingly, these can be less demanding than civilian applications, which often require a higher degree of reliability and redundancy."[17] Anticipating that GPS's military oversight would remain a point of contention as GPS's commercial use outpaced its military use, President Clinton's 1996 PDD created the Interagency GPS Executive Board, a joint civil-military executive board charged with oversight of GPS, jointly co-chaired by the Department of Defense and the Department of Transportation.[18] President George W. Bush issued a policy memo in December 2004 stating that membership will include equivalent-level officials from the Departments of State, Commerce, and Homeland Security, the Joint Chiefs of Staff, and NASA, while the Chairman of the Federal Communications Commission will participate as a liaison.[19]

Discontinuation of Selective Availability

Partly in response to demands of commercial users, the precision provided by DGPS's, and to the threat of the EU's Galileo and Russia's GLONASS, the White House decided in May 2000 to turn off SA – six years ahead of schedule. "This decision was part of a larger effort to make GPS more responsive to civil and commercial users around the globe. Principally, the decision was driven by a fear that continuation of SA created doubts about the willingness of the US to provide what had become a critical global infrastructure, and it had acted as an incentive for other nations to build their own satellite navigation systems."[20]

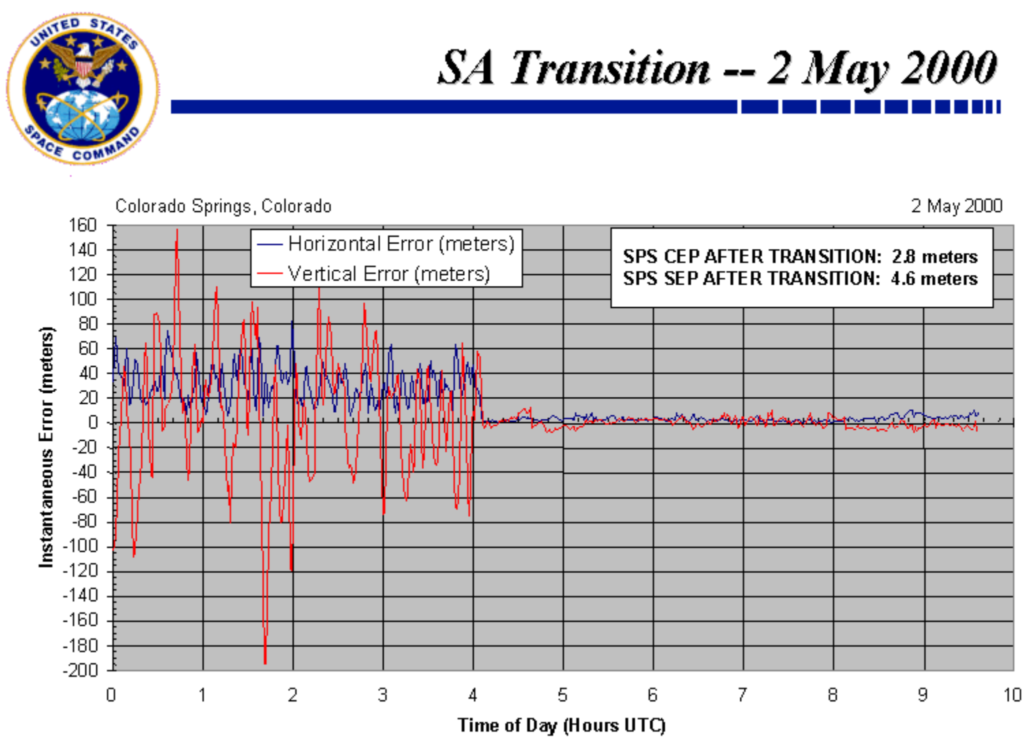


Figure 1 Transition of Selective Availability to Zero

The dramatic improvement in the SPS, following the removal of SA at 0000hrs on 2 May 2000, is graphically represented in the above US Air Force Space Command slide.[21] "Spherical

Error Probable (SEP) is the radius of a sphere containing 50 percent of the individual fixes – somewhat analogous to the three-dimensional median location. The two-dimension equivalent of SEP is Circular Error Probable (CEP), the radius of a circle which has a 50 percent probability of encompassing the true horizontal position."[22]

The end to SA was a significant acceptance of the needs of civilian GPS users around the world in an ever-widening set of applications, including air; road; marine and rail navigation; telecommunications; emergency response; oil exploration; and mining. It recognized GPS's dual-use nature and expressed the US government's wish to treat civilian users as much like military users as possible. As President Clinton stated in his May 2000 decision to stop degrading GPS precision, the improvement in precision caused by elimination of SA meant that "civilian GPS users would be able to pinpoint locations 10 times more accurately,"[23] from no less than 100 meters resolution to below 10 meters resolution. Perhaps more importantly, it removed "a significant irritant which constantly reminded users of the US military's control of GPS."[24]

While recognizing that global transportation safety, scientific, and commercial interests could best be served by discontinuation of SA, the Clinton administration reserved the right to deny civilian access to GPS in circumstances where it compromised national security. As President Clinton stated in his 1 May 2000 statement, "We have demonstrated the capability to selectively deny GPS signals on a regional basis when our national security is threatened."[25] Shortly after Operation Enduring Freedom began in early Oct 2001, a Schriever AFB spokesman added that a denied GPS region could be very well defined. That would mean only military GPS receivers with a current crypto key, "such as those in planes, ships and in the hands of US Special Forces operators, would work within the targeted area."[26]

GPS Modernization

Long before the European Commission was developing its initial plans for Galileo in the mid-1990s, the US was upgrading its GPS satellites to promote further military and commercial use and significantly improve precision, availability, and reliability. Eleven first-generation GPS satellites, known as Block-I or developmental satellites, were launched between 1978 and 1985. They had neither SA (and were therefore fully available to civilian users) nor anti-spoofing security features, they validated the GPS concept, and some were still functioning 10 years after launch despite their design life of five years. Twenty-eight Block-II and -IIA (for Advanced) satellites were launched between 1989 and 1997 and incorporated SA and anti-spoofing security features. From 1997 to 2004, the US Air Force launched 12 Block-IIR (for Replacement) satellites; these enhance system accuracy by using a technique of ranging and communication between the Block-IIR satellites and have a design life of 10 years.[27] Since 2005, three of eight planned Block-IIR-M satellites have entered orbit; these broadcast the new military M-code and a second civilian SPS frequency.[28] Whereas military receivers currently require access to GPS's Coarse Acquisition signal to acquire PPS, the M-code has been designed for autonomous acquisition, enabling receivers to acquire the M-code directly.[29] In addition, the M-code is backward compatible with existing military receivers, is less susceptible to jamming, and enables over-the-air rekeying of military receivers.[30]

Scheduled for launch in 2008, the fourth-generation satellite, Block-IIF (for Follow-on), will have many improvements over its predecessors including a 15-year design life, advanced atomic clocks, improved reliability, increased and adjustable signal power, and the addition of a third civil signal for services where lives are at risk, such as commercial aviation.[31] Scheduled to begin launching in 2013, GPS Block-III (commonly referred to as GPS III) satellites will be the first to be fully compatible with Galileo satellites and are expected to increase signal transmitter

power 500-fold, multiplying its resistance to jamming. In addition to all the features of the previous GPS satellites, GPS III will transmit a more robust signal and provide precision approaching real-time unaugmented one-meter, as more GPS III satellites are placed in orbit; this would improve to less than one meter precision when augmented by signals from Galileo satellites.[32] In this way, GPS III precision could very likely rival that expected of Galileo. Boeing, the prime contractor for GPS III satellites, stated in a January 2007 press release that "GPS III sets a new standard for space-based navigation…GPS III will provide transformational capabilities, such as anti-jamming, to our customer and our warfighters, along with better precision and interoperability with Europe's Galileo system for our commercial and civil users."[33]

GPS Accuracy

GPS's high level of accuracy is largely due to the extremely accurate atomic clocks on board each satellite (depending on the model, a GPS satellite has either three or four clocks; only one clock is operational on each satellite at a time, the others are backups), ensuring that its pulses are sent at precise time intervals. During Operation Desert Storm, "most users in the Persian Gulf region obtained positional accuracies within 7.5 to 13 meters" and velocity accurate to within 0.1 meter/second, based on 11,000 navigation solutions for the various monitoring stations and comparing them to their known locations.[34] The SPS with SA now turned off delivers near-equivalent position accuracy as PPS; PPS has the advantage of dual-frequency for improved ionospheric correction, not a significant factor in the mid-latitudes with little to no sunspot activity.[35] Beginning in 2012, when 24 GPS satellites in orbit are able to broadcast SPS on two frequencies (as the three operational Block-IIR-M satellites already do), there will be no difference between PPS and SPS accuracy.

As a part of its core mission, the Air Force Space Command's GPS Operations Center (GPSOC) monitors GPS PPS performance and periodically produces reports documenting operational performance trends and characteristics. Table 1 compares GPSOC's GPS performance measurements during calendar year (CY) 2005 to the previous three years, and it can be seen that GPS performance in 2005 followed a general trend of improvement. (The data in the last row of Table 1 combines horizontal and vertical predicted precision values into a single three-dimensional (3D) position error parameter.)

Table 1. GPS Operational Performance Summary

Ops Performance Parameter	**CY 2002**	**CY 2003**	**CY 2004**	**CY 2005**
PPS 95% Horizontal Error	2.36m	2.06m	1.86m	1.78m
PPS 95% Vertical Error	4.13m	3.59m	3.22m	3.08m
PPS 95% 3D Position Error	4.77m	4.18m	3.76m	3.59m

Source: GPS Operations Center, *GPS Operational Performance Report for Calendar Year 2005*, 27 Jan 2006, page 1

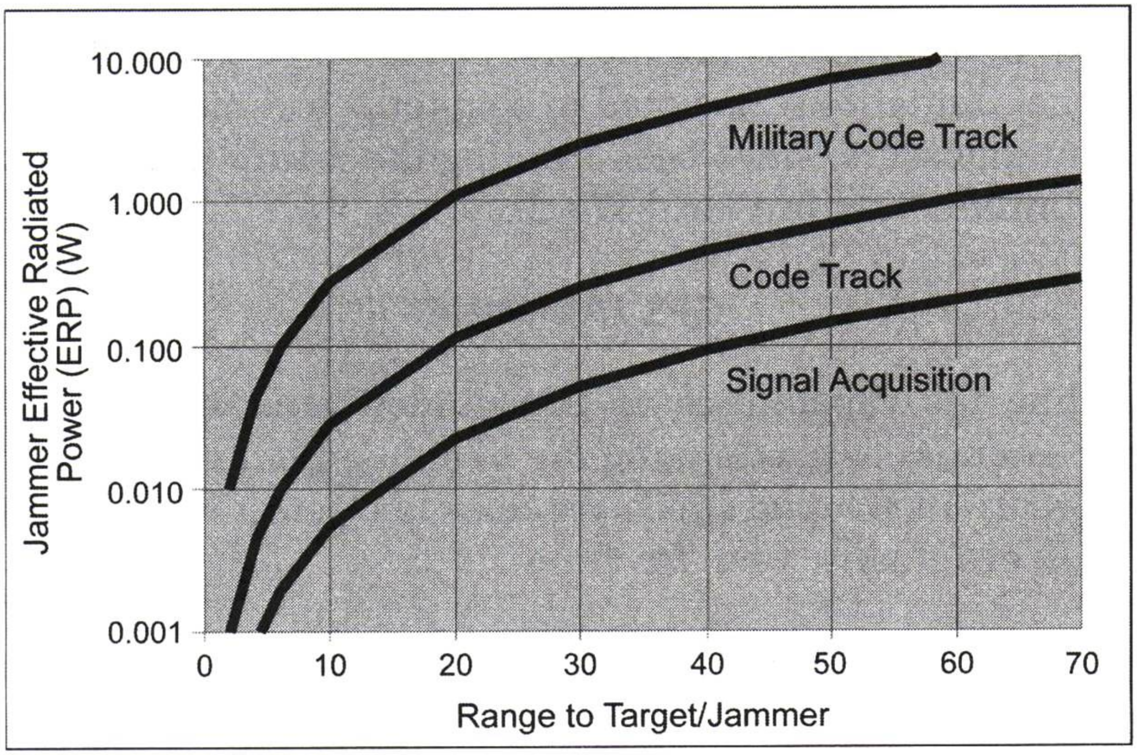
The GPSOC stated that as older GPS satellites, which perform relatively poorly compared with current models, are decommissioned and replaced by newer GPS satellites, the constellation will become more precise and thus continue the trend of increasing GPS's positioning precision.[36] In addition, several technical improvements to the ground portion of GPS, such as adding more monitoring stations, conducting more frequent atomic clock updates, and minimizing the effects of atmospheric distortions on GPS signals, have further enhanced overall system accuracy.

GPS and Navigation Warfare

The more the US military has come to depend on GPS, the more it must contemplate navigation warfare, or NAVWAR, being waged against US and allied forces, the object of which is to deny navigation capability to an enemy. Although the integrity of the GPS signal was maintained during the 2001 war with Iraq, attempts to corrupt it underscored the need to protect weapons and navigation systems that rely on GPS.

There are two kinds of GPS countermeasures. The simpler is jamming, where a noise signal covers the GPS signal and causes the receiver to break track. When it comes to jamming, its low signal strength is GPS's Achilles heel and the graph in Figure 2 below shows how vulnerable the GPS signal is to jamming. Less than one watt of jamming will prevent a civil receiver from tracking GPS across a range of 25 km; a one-watt jammer, antenna, and battery for 24 hours of operation will fit into a container the size of an aluminum beverage container and is relatively simple to construct; GPS jammers producing several hundred watts of effective radiated power (ERP) could be easily mounted with their power supplies in pickup trucks.[37]

Figure 2. ERP Needed To Fully Jam GPS Signals At A Given Range (KM)



Source: Michael Russell Rip and James M. Hasik, *The Precision Revolution: GPS and the Future of Aerial Warfare*, (Annapolis: Naval Institute Press, 2002), 278.

The technology and ability of GPS receivers to resist jamming varies greatly. Acquiring the PPS signal (only possible with a military receiver and a current crypto key) improves jamming resistance by 10 decibels, and using a null antenna can boost a receiver's jamming resistance by 15 decibels.[38] While some US military anti-jam receivers lock onto eight rather than four satellites and average some of their data, others employ different techniques. United States defense contractor Lockheed Martin developed an anti-jam GPS receiver in 2000 for its Joint Air-to-Surface Stand-off Missile, which relies on GPS to provide guidance to a target. Lockheed's anti-jammer "uses digital technology to detect jamming signals and null them," and it "digitally steers the GPS receiver's antenna toward the GPS satellites and away from signals from the jammer."[39] In January 2003, the US Air Force asked Boeing Co. to develop an anti-jam antenna for its $20,000 GPS-guided Joint Direct Attack Munition (JDAM). The new antenna,

comprised of a tail kit attached to a dumb bomb including adjustable fins, a control computer, an inertial guidance system and a GPS receiver, will be able to recognize and ignore a jammer's signals.[40]

An extreme method of handling GPS jamming signals would require first localizing the jammer and then dispatching an aircraft or missile to destroy it, which could be costly if there are multiple jammers. The US military does possess such an offensive capability though; for example, the Block V upgrade to the AGM-88C HARM (High-speed Anti-Radiation Missile), fielded in 1999, was a software update and introduced a home-on-jam capability, including the option to home on high-power GPS jamming equipment.[41]

GPS's known vulnerability to jamming drove Iraq to purchase GPS jammers from Aviaconversiya, Ltd., a Russian company that has been promoting its GPS jamming systems at military hardware shows since 1999. Aviaconversiya claimed its products could jam GPS signals for a radius of several miles, and "the Iraqi military used at least six of these high-powered GPS jammers, which cost at least $40,000 each, during the war in 2003. All six were quickly eliminated by US forces over the course of two nights."[42] GPS jamming can be traced back to its origin; "We've killed every GPS jammer that's come up -- with a GPS weapon -- so that hasn't worked out very well for them," said then Air Force Lt Gen Michael Moseley, commander of the US-led coalition air forces, at a press conference in April 2003.[43]

The other GPS countermeasure is spoofing, or broadcasting a pseudo-GPS signal designed to confuse GPS receivers by providing false and potentially misleading positioning data to the user, especially when GPS is used to compute target location coordinates based upon their position and the range and azimuth to the target. "If the GPS receiver gives the user a false reading for his location, the target location coordinates based on this false position will also be

wrong by the same amount and could result in collateral damage," according to a 2005 video published by the NAVSTAR Joint Program Office.[44] Due to the inherent anti-spoofing qualities of the PPS signal, a civilian GPS receiver using the SPS signal is much more likely to succumb to spoofing and report a false position than a military GPS receiver using the PPS signal.[45] For this and other reasons, the DOD mandates that its combatant users acquire, train with, and use GPS systems capable of receiving the encrypted military PPS signal.[46] In addition, many missiles and aircraft employ tightly-coupled inertial navigation systems and GPS receivers, making the GPS receiver not only significantly more resistant to broadband jamming, but also to signal spoofing, where the inertial inputs can be used as a sanity check on the GPS receiver's data.[47]

European Geostationary Navigation Overlay Service

Recognizing the fast-growing military and economic applications of satellite navigation, the European Commission (EC) embarked on its first venture into satellite navigation in 1995 when it called for the development of a space-based differential GPS system. The European Geostationary Navigation Overlay Service (EGNOS), fully operational since July 2005, consists of three geostationary satellites and a network of ground stations. It uses the signals from the American GPS and Russian GLONASS satellite constellations to provide users in a geographical area covering Europe, the Atlantic Ocean, the Indian Ocean, South America, Africa, the Middle East and Central Asia a high-performance navigation and positioning service superior to the unaugmented GPS signal currently available in Europe.[48] Per the European Space Agency (ESA), EGNOS will provide precision on the order of 2-4 meters vertical and 1-3 meters horizontal.[49]

The EGNOS is the first phase, GNSS 1, of the European Union's policy on a Global Navigation Satellite System (GNSS); the second phase, GNSS 2, calls for the launch of a second

generation of systems that independently provides a full civilian satellite navigation system, which the EC later renamed as "Galileo." Experience with EGNOS helped European scientists to develop much of the required technical capability and know-how in the advanced sector of satellite radio navigation, essential to the development and fielding of Galileo.[50]

The EC highlights has two significant advantages of EGNOS over GPS and GLONASS, both of which the EU will incorporate into Galileo. First, EGNOS's purpose is purely civilian, and its civilian management will guarantee reliability and availability. Second, EGNOS provides the user with information on the reliability of the system by transmitting integrity messages within six seconds whenever the quality of the signals received falls below certain thresholds. "When you get a GPS navigation signal, how do you know you can trust it? EGNOS will tell you whether you can trust the signal," said Laurent Gauthier, the EGNOS project manager at the European Space Agency.[51]

Russia's Global Navigation Satellite System (GLONASS)

The Global Navigation Satellite System (GLONASS), developed and deployed as the counterpart to the American GPS, is run for the Russian government by the Russian Space Forces and its functioning is coordinated by units within Moscow's defense ministry. Like GPS, the complete nominal GLONASS constellation consists of 24 satellites, 21 operating and three on-orbit spares; also like GPS, GLONASS was designed for partial civil use and broadcasts its civil signal on one frequency and its precision military signals on two frequencies. GLONASS does not have an SA feature, and the Russian government has claimed that it has no intention to intentionally degrade its civil signal, so the full accuracy of GLONASS will be available to users at all times.[52]

The Soviet Union placed the first operational and test GLONASS satellites in orbit in 1982, and at peak efficiency the system offered a horizontal positioning reading accurate to within 57-70 meters. During 1995, the Russians launched nine GLONASS spacecraft, enabling completion of the GLONASS constellation with 24 primary and one spare satellite. No launches occurred for the following three years, however, and due to their relatively short three-year average lifespan, only 11 spacecraft were operational on 30 December 1998.[53]

GPS and GLONASS signals are not compatible, though a handful of companies offer combined GPS/GLONASS receivers with two sets of signal-processing hardware, principally for the surveyor market. GLONASS has been to this point a fairly good GPS augmentation system, filling in at times of day when not enough GPS satellites are visible for high-precision use. But that may change as more Galileo satellites broadcast their signals, and GLONASS risks fading into obsolescence. The GPS-GLONASS Interoperability and Compatibility Working Group held its third meeting in December 2006 to address this issue; a statement from the meeting said that it "resolved many questions regarding interoperability and compatibility between GPS and GLONASS systems," but did not indicate whether GLONASS would modify its signal, a costly endeavor, to be compatible with GPS and Galileo.[54]

In November 2006, Russian Defense Minister Sergei Ivanov laid out the plans for GLONASS, noting that, "Today, 14 spacecraft are in orbit," with another three satellites to be launched December 25, 2006. By the end of 2007, GLONASS is intended to cover all of Russia, which will require 18 satellites. (Three GLONASS satellites were successfully launched into orbit on December 25, 2006.)[55] He added that the planned global coverage of the system by the end of 2009 will require 24 satellites.[56] This aggressive schedule is facilitated by a Russia-India joint venture, concluded at the December 2005 summit between Indian Prime Minister

Manmohan Singh and Russian President Vladimir Putin, in which India would launch two GLONASS-M satellites (an advanced GLONASS satellite with a seven-year lifespan) on its Geosynchronous Satellite Launch Vehicle platforms and share development costs of the next-generation K-series GLONASS satellites (several internal improvements, half the weight of the M-series spacecraft, and a 10-12 year lifespan.) In addition, Russia and India will jointly develop and market GLONASS receivers for commercial use.[57] "At present India is the only country with which we want to develop all aspects of GLONASS," Defense Minister Ivanov said during the seventh Indo-Russian summit in Bangalore on 23 January 2007.[58] India's search for a GPS system had seen it engage in negotiations with the Galileo project, but the deal had run into security concerns. Indian negotiators were not satisfied that the information accessible on the proposed system was adequately firewalled against individuals and possible military users. GLONASS will attract international interest only if users can be assured that the system will meet its navigational requirements; India's satellite launch capabilities and technological expertise will help GLONASS make great strides toward establishing a record of consistent performance characteristic of a mature and reliable navigational system.

China's Compass Navigation Satellite System

On 11 April 2007, a Beidou (Big Dipper) navigation satellite was successfully launched into geostationary orbit about 22,300 miles above the Earth. The Chinese previously had launched four other Beidou satellites; two in 2000, one in 2003, and another in February 2007.[59] These Beidou satellites are the first group in a series of space-based navigation platforms called the Compass Navigation Satellite System. According to China's state-run Xinhua News Agency, the fleet should become operational in 2008 for much of China, but it could take several more years before it can be used worldwide. Xinhua further stated that China's vast size warranted a

domestic system that would improve on the "rough" details provided by the civilian-side GPS used around the world today.[60] “Experts said that the system is operating well and has played a significant role in cartography, telecoms, water conservation, transportation, fishery, prospecting, forest fire monitoring and national security.”[61] Previous reports said Compass will provide positioning accuracy within 10 meters, velocity accuracy within 0.2 meters per second, and timing accuracy within 50 nanoseconds.[62] In general, China is substantially ramping up its space activity, and this launch came only a few weeks after China prompted expressions of concern from the US by destroying one of its own ageing meteorological satellites with a missile-launched “kinetic kill vehicle.”

GPS, Galileo and GLONASS all use satellites that orbit the Earth. Compass will position five of its satellites in geostationary orbit above China; they will not move relative to the Earth’s surface. Thirty other satellites will orbit similarly to the other three GNSS systems.[63] To date, the plans for this network have been shrouded in secrecy, with officials repeatedly declining to comment on the project. However, Xinhua lifted the veil slightly and said that there were plans to launch other navigation satellites in 2007 to create a network covering the whole of China and parts of some neighboring countries by 2008. The Compass system would then expand to offer global coverage with the creation of a constellation of 30 medium earth orbit satellites, Xinhua said, but gave no timetable for when this would be operational. “Analysts have suggested that the expanded Compass system would use the same radio frequencies as Galileo and possibly GPS, making it more difficult for adversaries to jam the network in case of war.”[64]

Compass’s expansion into the civilian arena could pose a challenge to the commercial success of Galileo. Experts had believed that China planned to use its Compass system only to support its military forces, and EU backers of Galileo planned on selling receivers and

commercial signal subscriptions throughout China. But in November 2006, China announced that in addition to its encrypted military service, the Compass system would begin providing an open level of service with 10-meter precision for commercial users in 2008.[65] This will likely place a large pool of potential Chinese Galileo customers in a position to take the best offer available, possibly significantly impacting Galileo's business plan. Ironically, while China's government and firms are investing €200m in the Galileo project with related facilities and research into commercial applications, Compass is at the same time shaping up as a potential competitor to Galileo.[66]

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Chapter 3

Galileo

Program Overview

As early as June 1994, the European Commission displayed dissatisfaction with its strategic dependence on the US GPS. The EC stated that if Europe did not act promptly, it would not only remain dependent on the US, but would also be shut out of the "huge associated market for user equipment," as the US was setting requirement standards and certification schemes.[1]

In 1998, the European Commission identified several concerns with continued reliance on third countries' positioning and navigation systems, including:[2]

- A perception by the EC that European sovereignty and security would be compromised if Europe's key navigational safety systems were beyond European control;

- The judgment by the EC that present systems could not fully meet civil users' performance requirements;

- The desire to ensure that European users are not at risk from changes in the service or excessive future charges or fees; faced with a dominant position or virtual monopoly, it would be difficult to resist such charges and perhaps impossible to develop alternatives quickly;

- The capacity for EU industry to compete in this lucrative market (predicted at the time to become a global market of €50 billion by 2005) would be seriously constrained. Europe's

capacity to compete in the market for services could be undermined if it did not have equal access to the technological developments in the system itself.

Galileo Takes Form

Citing several GPS shortfalls - specifically weak and intermittent GPS signal penetration, poor precision, and the ever-present risk of civil users being cut off of GPS in the event of a crisis due to its predominantly military character - the European Union's Transport Council asked the EC in July 1999 to begin the Galileo definition phase, the first step in an effort to provide the first satellite positioning and navigation system specifically for civil purposes. The Galileo program was officially initiated at the December 2001 European Council meeting at the Royal Palace of Laeken in Brussels, Belgium, when the European Union, represented by the European Commission, and the European Space Agency (ESA)[3] committed to the development of a space-based positioning and navigation system of its own that met the criteria for precision, reliability, and security. Facilitating this decision was ESA's prediction of an associated program for equipment and services valued at around €10 billion per year, and the expected creation of more than 100,000 highly-skilled jobs.[4]

An obvious benefit of the Galileo program is its potential to deepen European integration and strengthen the EU's identity. With the European political identity seemingly inchoate, a unified European effort to take the technological lead in a high-profile strategic system – in keeping with the Lisbon growth strategy, to make EU "the most competitive dynamic knowledge-based economy in the world" by 2010, as put forward by the EC in Lisbon in March 2000 – is a strong political message, albeit an expensive one, intended to strengthen European integration by developing key strategic sectors.[5]

One of the principal strategic sectors is space; and Galileo is an optimal vehicle for pursuing development in that sector, many Europeans recognized this. In the summer of 2003, the EC and the ESA formally entered into the Galileo Joint Undertaking to manage the developmental phase (launching the first experimental satellite, developing four more satellites, and validating the concept) of the Galileo program, to mobilize the required funds, and to manage the integration of Galileo and EGNOS. The EU's stated goal was that, when fully operational, Galileo would offer precision superior to the fielded version of GPS, due to the structure of its satellite constellation and the robust ground control system; precision of less than 1 meter has been frequently claimed by the EU and the ESA. In addition, the EC has consistently stated that Galileo will offer superior reliability because it will convey signal integrity information to the user in near real time and also because it is intended to cover areas of northern Europe that GPS does not.[6]

Declarations of Galileo's superior precision over GPS's appear prominently in the EU's numerous Galileo marketing brochures, which are designed to attract large amounts of foreign investment capital – a bold claim to make of a system that has fielded only one of 30 satellites in comparison to a system that has been fully operational for over two decades. The Galileo brochures state that, due to the geometry of Galileo's proposed satellite constellation and the modern technology of its satellites and ground stations, Galileo's signal will be more precise than that of GPS. However, the upcoming GPS-III satellites will improve GPS's precision from today's three meters to one meter, and GPS users could see a further improvement in precision to less than one meter when augmented by signals from Galileo's compatible satellites.[7] In this way, GPS III's precision will very likely rival that of Galileo when both systems are fully operational.

The core of the Galileo system will be the global constellation of 30 satellites in medium Earth orbit. The mechanism for creating the constellation will be a series of rockets, each carrying multiple satellites, with a dispenser able to deliver into orbit up to six spacecraft simultaneously. Galileo's ground station network will consist of sensor stations to monitor the satellites, two control centers to manage the satellites' navigational signals and monitor the system's integrity, and uplink stations to communicate with the satellites.[8]

Program Phases and User Services

The Galileo infrastructure is being implemented in three phases:

Phase 1. The Development and Validation Phase (2002-2008): This phase includes the launch of the first experimental satellite, development of four more satellites and ground-based components, and validation of the system in orbit. This phase's €1.1 billion cost is being shared equally by the European Commission and the European Space Agency.[9]

Phase 2. The Deployment Phase (2009-2010): This phase consists of construction and launch of the remaining 26 satellites and installation of the complete ground segment. A consortium of eight European aerospace and defense companies, communications device makers, and satellite manufacturing companies[10] is expected to contribute two-thirds of the €2.3 billion needed to launch the satellites. The remaining one-third of the funds will come from EU transportation funds.[11]

Phase 3. The Commercial Operating Phase (2011 and beyond): This phase includes routine operations and maintenance of the system for a minimum of 20 years. The Galileo Joint Undertaking will select a commercial operator, or concessionaire, to lead Galileo through this phase. The concessionaire will have to meet the annual operations, maintenance, and replenishment charges, calculated at around €220 million.[12] The ESA anticipates public funding

will be required until 2015, when the revenues generated from the sale of Galileo services should exceed maintenance costs.[13]

Galileo is expected to offer several layers of service. The Open Service will be oriented toward mass-market applications, providing free-of-charge accessibility by any user with a receiver. It will use a combination of Galileo and GPS signals to improve performance when necessary, such as in urban areas, but will not have a service guarantee. The Safety-of-Life service will be as precise as the Open Service, but will be optimally integrated with EGNOS to deliver a high integrity and guaranteed signal. This service will be certified and oriented toward transport applications (such as aircraft landing assistance and ship guidance through coastal waters) where human lives could be endangered if the performance of the navigation system degrades without near-real-time notice. The fee-based Commercial Service will add two encrypted signals to increase positioning precision, and will be aimed at market applications requiring higher than Open Service performance, such as those that offer service guarantees or precise timing services. The Search and Rescue Service will enable a user to send a distress signal and obtain acknowledgement of its receipt. The encrypted and anti-jam Public Regulated Service (PRS) will be used by civil authorities such as police departments, emergency medical services, fire departments, coast guards, and customs agencies, and its robust signal will resist jamming and spoofing.[14]

Galileo will broadcast its signals on two frequencies, one of which is already used by GPS. Sharing this band with GPS will be on a non-interference basis, in order to avoid affecting GPS services while offering users simultaneous access to GPS and Galileo and minimizing terminal costs and complexity.[15]

Economic Benefits

Today there are only two independent global satellite navigation systems, and both were designed for national security needs during the Cold War: Russia's GLONASS and the United States' GPS. GLONASS is not fully operational and is plagued by low levels of precision and reliability, problems that have worsened with Russia's political and economic crisis during recent years. Although this system will likely improve with India's contribution of launch support and technical assistance to the Russian program, GLONASS cannot realistically be considered as a competitive threat to European ambitions at this time.

The ESA has argued that, relatively speaking, Galileo is not an expensive program. In 2005, the ESA estimated the development and deployment costs, including launching the 30 satellites and installing the network of ground stations, to be €3.8 billion; annual operations, maintenance, and replenishment costs were estimated at €220 million. As ESA was quick to point out, this was equivalent to the cost of building 150 kilometers of highway, and was even less than the cost of the fifth terminal now being built at the Heathrow Airport.[16] Furthermore, the international accounting and consulting firm, PricewaterhouseCoopers, conducted an independent analysis of Galileo's proposed infrastructure and services in 2001 and concluded Galileo's cost/benefit ratio to be much higher in comparison to any other European infrastructure project thus far completed.[17]

Galileo proponents have consistently stressed the potential commercial benefits from the construction and operation of an independent European satellite-based positioning and navigation system ever since the EC feasibility studies in 1999. In discussing the implications of Europe's GPS dependence for its Common Foreign and Security Policy, the EC stated "Europe is now in a position to decide whether to develop a new system. By contrast, failure to act would

strengthen the present US market dominance and leave Europe entirely dependent on the US for many security-related matters."[18] The EC recognized both the economic benefits Europe would gain by developing Galileo and the sense of security from controlling the system on which its safety critical services would depend. Accordingly, EU discussions leading up to the decision to proceed with Galileo focused on job creation, technological spillover effects, and monetary benefits, provided the EU could break into the satellite navigation market at the right time; that is, before the advanced GPS III constellation becomes fully operational and marginalizes the advantages of Galileo over GPS.

Europe's approach to Galileo is unique in its stated focus on civilian, and categorically non-military, applications of space research programs and the diffusion of knowledge and related advantages to the benefit of the Galileo community. In a key aspect of their 1999 argument for Galileo, the EC emphasized the fact that the presence of European industry in this high technology field would greatly help secure and augment employment. It estimated that putting the satellite navigation infrastructure into place would create 20,000 jobs; its operation would create 2,000 permanent jobs with new employment opportunities in applications (hardware and services); and anticipated that, by 2008, approximately 100,000 jobs in direct, indirect and induced employment depended on going ahead with Galileo.[19] In 2006, the EC increased its job creation estimate to 150,000 jobs, primarily in the high-tech sector.[20] Building Galileo's infrastructure and creating a large number of highly-skilled jobs will likely have significant spillover effects to the rest of the EU economy. In addition, Galileo's high value-added manufacturing can lead to gains in the EU's innovation, productivity, rapid development of advanced products, and the accumulation of intellectual capital.[21]

Galileo's EU proponents see the potential for significant economic benefit to the Galileo operator community if they can break into the market quickly. According to the EC, European industry's market share in satellite navigation markets in the late 1990s was only around 15 percent of the European market and 5 percent of the global market. The satellite industry and its EU supporters framed the need to support Galileo in terms of ensuring a future European position in the space segment and end-user equipment markets around the world. According to the EC's estimate in 2004, the global market in products and services linked to satellite-based positioning and navigation technology was on the order of €10 billion per year; growing at an annual rate of 25 per cent it was due to rise to about €300 billion in 2020. In addition, the EC estimated that some three billion receivers would be in service by 2020.[22] However, PricewaterhouseCoopers's 2001 analysis stressed that Galileo begin Phase 3 operations by 2008 in order to secure an increased share for Europe of the user equipment and related technologies markets. These markets would be in a rapid growth phase by then, and GPS III was expected to commence operations one or two years thereafter. According to PricewaterhouseCoopers, Galileo will become established only if it is in the market in time to gain acceptance in the launch of new equipment and services which will accompany this change. If this happens before GPS III comes on line, the 2001 PricewaterhouseCoopers review estimated that the annual sale of Galileo receivers would increase from 100 million units in 2010 to some 875 million units by 2020 which represents market share rising from 13 per cent to 52 per cent.[23] Since that 2001 estimate, the launch of the Galileo satellite constellation has slipped to 2010; but Galileo's window of opportunity is still open, as GPS III's launch has slipped to 2013.

Revenue Streams

A number of potential Galileo revenue streams have been identified, some of which depend on regulatory action. The future concessionaire, leading Galileo's Phase 3 operations, would receive payment for the sale of the various services generated by the Galileo system.

One potential revenue stream would be the controlled-access services (those fee-based services controlled via encryption, including reliable signals for safety-of-life applications, such as civil aviation and maritime transport) available to subscribers in return for certain fees. In some cases, the use of these services might be mandatory, such as access to infrastructure or monitoring fishing activities, freight and coach transport and road safety services. Insofar as Galileo allows existing ground-based air navigation facilities to be replaced and provides a better and more reliable service to airlines, it can be expected that airlines will contribute to the revenue stream.[24] There is precedent for this: the International Maritime Organization has required internationally registered ships to carry GNSS equipment since 2000, and GNSS is an integral part of the Communications, Navigation, Surveillance/Air Traffic Management concept adopted by the International Civil Aviation Organization.[25] However, industry officials believe that persuading airlines, shipping companies and civil engineering groups to pay for the extra precision will be difficult. "Our position is that it is not really clear at this point that we need this paid service; we already have GPS for free, and we will have basic Galileo free of charge, and for now those are sufficient," said Vincent De Vroey, general manager for technical operations for the Association of European Airlines in Brussels, which represents more than 30 European airlines.[26] If revenue from industry does not come through, European taxpayers could end up footing the bill for the system for several years, according to Peter Marchlewski, general counselor of the Galileo Joint Undertaking until December 2006.[27]

Another possible revenue source would be a tax on receivers and for satellite-based radio-navigation services. The tax would need to be introduced throughout the EU and be applicable to all receivers sold in or imported into the EU, including equipment for in-car-navigation, leisure activities, etc. According to the EC, "This would be entirely in line with the general EC philosophy of marginal infrastructure cost charging and could be limited to very small sums."[28] Similar taxes are already used in a large number of EU member states for certain products, such as photocopiers and video cassettes, and for certain services, such as public television and radio broadcasting.[29] A tax of €20 on each receiver would provide a revenue stream of €140-205 million annually and could go a considerable way to filling the financing gap for long-term operations and maintenance of Galileo.[30] It would also be possible to introduce, although more difficult to implement, an annual operating license fee for the reception of satellite navigation signals.

Frequencies: From Competition to Cooperation

Frequency Overlay

In 2001, it appeared that GPS and Galileo would compete for the same radio frequency spectrum. Galileo planned to use a frequency for its Public Regulated Service that would conflict with the frequency the US would begin to use in a few years for its second military signal, the GPS M-code, planned to be broadcast first from seven GPS-IIR-M satellites,[31] three of which have been launched since September 2005. The signal characteristics of GPS's M-code would enable the US, when necessary, to jam its own civilian frequency in a conflict zone to prevent enemy forces from using it, without affecting the M-code's availability, thus providing the US and its allies exclusive and uninterrupted positioning and navigation services. Likewise,

the US wanted the ability to jam Galileo without rendering ineffective the GPS M-code signals. Some in the US speculated that this “signal fratricide” envisioned for Galileo and the GPS military signal was intentional, designed to force the US to jam its own signal in order to deny Galileo services to an opponent.[32]

In December 2001, this situation prompted US Deputy Secretary of Defense Paul Wolfowitz to write to the ministers of defense in those EU countries that were North Atlantic Treaty Organization (NATO) members to convey US concerns over the signal competition, highlighting potential damage to future NATO operations. Wolfowitz noted that the addition of any Galileo services in the same spectrum “will significantly complicate our ability to ensure availability of critical GPS services in time of crisis or conflict and at the same time assure that adversary forces are denied similar capabilities." He added that it was in the interest of NATO “to preclude future Galileo signal development in the spectrum to be used by the GPS M-code."[33]

The Move to Frequency Cooperation

Galileo’s potential signal interference with GPS raised resentment of many in the US, and both sides entered into four years of difficult negotiations. “Success in the negotiations was not predetermined, as Galileo had become an irritant in the transatlantic relationship”[34] but, in the end, the parties agreed to make the two systems compatible and interoperable rather than competitive.

In June 2004, a cooperation agreement was signed between the EU and the US which recognized the full autonomy of Galileo. In return for modifying Galileo’s signals to protect the GPS M-code, the US agreed to provide to Europe technical assistance in developing Galileo and to ensure that GPS-III satellites would conform to Galileo’s broadcast standards.[35] It would make Galileo’s signal “the de facto international standard,” said Charles Ries, the US State

Department's principal deputy assistant secretary for Europe.[36] This cooperation would aid the interoperability of the two systems, supporting a commercial desire of both the US and EU to develop straightforward and fully interoperable receivers.

Out of the Gate: Early Programmatic Challenges

Despite all its promise, Galileo faces some tough challenges. Only one satellite has been launched, in December 2005. The second satellite, originally scheduled for launch in April 2006, then September, and then December, is now set to launch sometime in 2007, according to ESA's general director, Jean-Jacques Dordain.[37] The EU schedule still shows all 30 satellites in orbit by the end of the decade.

The estimated cost of developing the system has soared far beyond the EC's 1999 cost estimate of between €2.2 and €2.9 billion[38] and is now projected at €3.8 billion.[39] EU officials attributed Galileo's cost overruns to increased security to prevent breakdowns, software upgrades, rising labor and marketing costs, and two additional test satellites needed to check the frequencies Galileo will use.[40] When operational, the EU expects Galileo to cost €220 million per year to operate. Even though it has fewer satellites than Galileo, the US Air Force states GPS costs about €576 million annually to operate,[41] suggesting that the EU may be underestimating Galileo's true operating costs.

And finally, recent arguments among EU nations to acquire a portion of Galileo's operations in their territory, in addition to power struggles among the eight consortium companies, have caused significant delays in Galileo's development and deployment schedule.[42]

System Availability: GPS vs Galileo

Central to the decision to develop and operate a separate, independent GNSS service is the EU's unease with continued US military control over GPS. Despite US assurances that the US intends to make GPS available on a continuous worldwide basis for the foreseeable future, the EU has adopted the view that GNSS continuity has become too important to be left under the control of the US military. One of Galileo's competitive advantages will be its continuous and reliable signal for all users, which will allow for the wider deployment of applications, especially commercial ones. The EU and ESA highlight Galileo's guaranteed availability as superior to GPS's by citing, for example, "the predominantly military character of GPS means there is always a risk of civil users being cut off in the event of a crisis."[43] Per Title 10 of the US Code, the DOD, as owner and controller of GPS, can indeed decide without notice to interrupt reception for reasons of national security.[44] However, the likelihood of GPS being turned off, even for a limited area of operations, is extremely remote. As Ralph Braibanti, director of Space and Advanced Technology for the US Department of State and head of the US delegation for GPS-Galileo consultations, stated, "The US provides the GPS civilian signal to a very high degree. The possibility of a limited shutdown is a red herring as we have never done it and do not plan to even in situations like we experienced in Kosovo and the Gulf region during Desert Storm."[45]

Further, if the US determines that it is necessary to jam the GPS civilian signal due to a crisis, not only will it limit that denial to a local area of operations to minimize collateral damage, the US will jam Galileo's positioning and navigation signals in that area as well. The 2004 US-EU agreement to cooperate on frequencies separated Galileo's civilian signal from GPS's military signal, enabling the US to jam GPS and Galileo civilian signals without harming GPS's military signal. In this way, Galileo's signal will not be available when the US decides to

turn off civilian GPS; GPS's civilian signal is just as available as Galileo is. Ironically, it is not Galileo's signal that offers continuous availability, as the EU advertises heavily in their glossy Galileo brochures, but rather GPS's encrypted military signal.

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Chapter 4

Geopolitical Perspectives

Galileo Furthers EU Sovereignty

The EU's European Security and Defense Policy (ESDP) has been criticized for being more of a declaratory policy, one not translated into concrete facts. An important landmark was reached in 2003 with the publication of the European Security Strategy (ESS), the European counterpart to the US's National Security Strategy (NSS); for the first time, the EU formulated joint guidelines for a coherent European international security strategy. Furthermore, EU missions in the Congo (Operation Artemis) and Macedonia (Operation Concordia) were the first autonomous EU external military missions, important milestones in operationalizing the ESDP. These missions, coupled with the ESDP's call for an even greater role for EU troops in humanitarian, peacekeeping, and peacemaking activities in conflict theaters outside the EU's borders, require information and data transmission on a global scale. Space technologies, especially programs like Galileo, represent the backbone of the infrastructure for future interventions in crisis theaters.[1]

Break From US Hegemony

The general expansion of the European space sector, including the security-related aspects of European space policies affording Europe a greater role in its control of space-based

information systems, also affects US-EU relations. Satellite radio navigation services supporting military and civilian applications across the EU have been provided by GPS. However, total dependence on a foreign power for a major feature of national infrastructure implied that one could never afford to upset that power to the point that it might threaten to withdraw that service. Therefore, the EU's policies would, to some degree, be bound to those of the US. Recognizing this issue, the EC highlighted in 1998 that there were serious limitations to Europe's sovereignty and security if its safety critical navigation systems remain beyond its control, forcing its continued reliance on other countries' positioning and navigation services.[2]

This concept was furthered in the EU's November 2000 European Strategy for Space. Still the most current European space strategy document, it highlights the strategic importance of space for economic and political growth in Europe, the global competitiveness of European industry as an industrial policy priority, and the importance of Galileo. When first written, it represented a "sharp break from the past, with space contributions to security and defense being seriously considered for the first time above the national level. The strategy calls for the EU to provide a common policy framework by integrating European space and making its history of fragmentation along national lines a thing of the past."[3] The March 2005 report of the EC's Panel of Experts on Space and Security concludes that during the Cold War it made sense for Europe to rely on non-European, i.e., US, space-based systems to support the EU's security, as Europe largely relied on the US for its collective security and had no need for an organic expeditionary capability. The report goes on to note that since the end of the Cold War, Europe's security situation has been rather different, and, with the establishment of the European Defense Force, Europe and its member states are increasing their capabilities to operate outside their borders in expeditionary forces on a variety of multinational military and civil operations.

This expert panel stressed that Europe could no longer assume a fortuitous coincidence of interest with the US.[4]

Galileo's business plan has clearly provided strong economic and commercial justification in its own right, but the Galileo program is unquestionably a political initiative as well. Underpinning EU support for Galileo is a strong desire for political autonomy, and developing a stand-alone European satellite system is evidence of the EU's desire to free itself from its dependency on the US in this area. In addition, given Galileo's expected technological spillover to military and aeronautical sectors, the decision to proceed with Galileo has wider significance in terms of EU autonomy. All in all, Galileo has become a symbol of Europe's technological capabilities and quest for further political independence. A central conclusion of the European Strategy for Space is that Europe should not remain dependent on foreign space infrastructure for strategic or commercial applications.[5] This followed from the belief that space was an essential national infrastructure, and that it would be foolish to depend on foreign sources of supply in this vital sector. France's President Jacques Chirac even went so far as to state that if Europe did not fund Galileo, Europe would become an "American vassal." [6]

US Reaction

An early US concern was that in moving forward with the Galileo program, Europe was spending funds on "a military service that was already provided by the US, funds that could be better spent addressing more pressing shortfalls in European military capabilities."[7] In relation to the US, defense spending among US allies has been declining for the past several years. The NATO member defense budgets have fallen from 2.49 per cent of gross domestic product in 1993 to 1.8 per cent of gross domestic product (GDP) in 2005, compared to the 3.7 per cent of GDP spent annually by the US.[8] In fact, according to US Army General Craddock, Supreme

Allied Commander Europe, only six of NATO's 26 member nations meet the organization's goal of spending a minimum of 2 per cent of their GDP on defense.[9] The US, understandably, would have preferred that the EU spend its limited funds on programs which yielded a greater return in military capabilities - especially those capabilities that would enable Europe to participate more evenly in joint operations - rather than divert its funds to provide duplicate satellite navigation capabilities.[10]

However, it quickly became clear that the EU rationale for Galileo had important economic, commercial, and strategic aspects that would outweigh any US protests in European decision-making. Thereafter, faced with the EU's concrete resilience to the program, US interests turned to ensuring the compatibility of GPS and Galileo, as well as the capability for the two systems to back each other up in case of malfunctioning.[11] User benefits from receiving signals from both satellite navigation constellations will include improved precision, reliability, and availability. Currently, GPS users may find their signal path to the satellite constellation significantly reduced by buildings, trees, bridges or other obstructions. With twice as many satellites visible in the sky, the probability will be much lower that signal blockage will interfere with the delivery of the GPS and Galileo navigation solution. Applications that are currently marginal, or impossible, will become more viable and cost effective for users. In addition, using interoperable frequencies will enable simplified receiver design (e.g., same antenna and circuitry), leading to lower costs for consumers.[12]

As warfare in the electronic arena continues to advance and the doctrine of "network-centric warfare" moves toward center stage, the use of satellite-based navigation and positioning systems has become essential for armed forces. As such, the US would oppose anything that would diminish the ability to deny access to positioning signals to adversaries in time of crisis,

and how the US would act to prevent hostile misuse of Galileo has been considered by senior US government officials for the past several years.[13] A glimpse of a possible course of action was provided in October 2004, when US representatives at a space conference in London warned that the Pentagon could attack Galileo's satellites if the system were hijacked by a hostile power such as China.[14]

Following a Trend: Airbus and Ariane Programs

"This is not the first time that US technological superiority has prompted innovation in Europe."[15] The EU and the ESA, together with other major interested parties, view the Galileo project as equivalent in potential to other successful large-scale European efforts such as Airbus and Arianespace, both of which were developed at a time when the US lead in airplane production and rocket launch sectors seemed out of reach.[16]

Airbus Industrie was set up by France, Germany, and England to offset US supremacy in the civilian airplane manufacturing industry; it now threatens Boeing for world dominance in the aircraft industry. The EU's decision to start building its own rocket launchers in the early 1970s, at a time when the United States was aggressively lobbying the non-Soviet world to use its cheaper space shuttle for satellite launches, produced Ariane, which successfully seized a very significant share of the satellite launch business when the US terminated commercial satellite launchings by the Space Shuttle in 1986 following the Challenger disaster. Virtually all space launch business had previously been performed in the US, but now Ariane has become the most widely used commercial launch system in the world.[17] As with the Airbus and the Ariane rocket programs, the expectation is that Galileo will follow suit and enable Europe to acquire a degree of technological independence in the satellite navigation sector.

International Cooperation

Foreign participation has provided a significant portion of the funds (on the order of hundreds of millions of euros) required for Galileo's development and deployment phases. Importantly, the involvement of foreign participants is a means to demonstrate European political leadership in space activities. Furthermore, as a global system, Galileo desires global partners to develop its full potential, so cooperating with countries beyond the EU's borders is essential. The ESA has thus been very interested in involving international partners to the Galileo project.

In October 2003, China became the first country to sign an agreement with the EU when the National Remote Sensing Center of China entered in the Galileo Joint Undertaking (GJU) with an investment of €200 million.[18] However, "the agreement remains a shell and the ultimate role China will play in Galileo is unclear."[19] In July 2004, Israel's Matimop, the Israeli Industry Center for Research and Development, coordinator of industrial R&D cooperation between Israel and the international high technology community, signed a membership agreement with the GJU, along with a contribution of €18 million. The agreement with Israel provided for joint work on research, satellite manufacturing, follow-up services, and marketing.[20] India signed up to participate in Galileo in September 2005, but withdrew over concerns of China's involvement and partnered with Russia on GLONASS. Similar agreements were signed with Ukraine in June 2005, with Morocco in November 2005 and with South Korea in January 2006. Steps have also been taken to involve several other countries, notably Norway, Argentina, Switzerland, Brazil, Canada, Australia, Saudi Arabia and Russia. The next step for the GJU is to determine the scope and the arrangements for cooperation with these third countries in future phases of the Galileo program.[21] "Third countries are more enthusiastic than certain European countries about

Galileo," EU Transport Commissioner Loyola de Palacio said in 2003, referring ironically to wrangling in the then 15-member bloc about funding for the project.[22]

However, the primary reason underlying international cooperation is not the need to meet the demands of individual countries, but the need to ensure interoperability with existing systems in order to promote European industrial and political know-how, stimulate the creation of system applications, penetrate the markets of these third countries, and install components of the terrestrial segment in certain parts of the globe. In addition, the fact that numerous third countries are associated with the program, and therefore share the European Union's interests in promoting Galileo, has resulted in a reduction of the technical and political risks involved. These worldwide links with future users make it possible to define more precisely user requirements. Lastly, international cooperation has provided a source of considerable funding to support the Galileo project.

Security Implications of China's Compass System

The heavy involvement of China in the Galileo program is particularly troubling for the US. A principal US concern with China's participation in the Galileo program is that this will allow China to transfer not only Galileo's advanced technology and knowledge to significantly enhance its Compass System, but also the advanced technology of the US. Recently, Lockheed Martin, a principal US defense contractor in the development of GPS-III satellites, and Astrium, one of Europe's leading satellite systems specialists and a subsidiary of the European Aeronautic Space and Defense Company (EADS), announced that a cooperative agreement had been signed to ensure the "interoperability, integrity, and optimization" of GPS III with the Galileo program. "This opens a new dimension of cooperation between two of the world's leading technology companies in systems that will benefit consumers for decades as the Galileo and GPS III come

on line," noted Reinhold Lutz, EADS senior vice-president for Earth Observation, Navigation, and Science.[23] However, as a result of China's significant involvement in Galileo, this agreement could benefit China by providing indirect access to advanced US technologies.

A recent commentary by Rand stated that "China has a history of using foreign technology and assistance to improve its military. This has increased its ability to copy weapon systems, to quickly integrate advanced technology into Chinese production lines, and to raise the technical expertise of their defense production sector. Chinese participation in Galileo is part of a gradual trend in economic and defense cooperation with Europe that in recent years has seen European governments and businesses sell to China technology that could be used for military purposes. This includes British micro- and nano-satellite technology that can be used in anti-satellite weapon systems, British airborne early warning radar that can be used in military aircraft, German engines that can be used in conventional submarines, and French and Italian technology that can be used in attack helicopters."[24]

In contrast to US concerns, senior EU officials have played down concerns about China's involvement in Galileo. Hans Peter Marchlewski, general counselor of the GJU, said the agreement with Beijing ensures that it is "explicitly excluded" from confidential signals affecting Western security. EU officials say the aim is to provide Beijing with a more sophisticated satellite system limited to civilian use.[25] However, European officials admit Beijing has shown interest at the top end of Galileo, including its encrypted and jam-resistant PRS. To remove any gray zones about its use, EU ministers confirmed in December 2004 that the PRS would be available only for military uses such as pinpointing locations, not for missile technology. Heinz Hilbrecht, a director at the European Commission, insists that the PRS "will not be offered outside the EU. It is very clear that certain confidential things, for example those linked to

intellectual property rights, will not be opened to the Chinese…. The Chinese will use Galileo for specific applications and we have no indication that they would use it for military operations."[26]

Meanwhile, China is doing little to mollify US concerns as to its 'peaceful' intentions. For example, a targeted attack in September 2006 on orbiting US intelligence satellites by a ground-based laser was confirmed by sensors on Kwajalein Atoll to have originated in mainland China.[27] Then, on 11 January 2007, China destroyed a defunct Chinese weather satellite by hitting it with a warhead launched on board a ballistic missile, making China only the third country after Russia and the US to shoot down anything in space. The message China has sent via these hostile actions is quite clear, "despite the opacity of China's space and military programs and deepening suspicion over its stated commitment to the purely peaceful use of space."[28] As US Vice President Cheney stated in February 2007, "Last month's anti-satellite test and China's continued fast-paced military buildup are less constructive and are not consistent with China's stated goal of a peaceful rise."[29]

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Chapter 5

The Five Steps the US Government Should Undertake

#1: Acknowledge the Existing Situation

The United States, through its provision of GPS free of user fees, has been able to promote its national interests by maintaining the system as an international public good. The benefits of providing such a system include international prestige, technological leadership, economic competitiveness, and the security that comes with having political control of a global resource. The US currently plays the role of political and technological leader and as such may see Europe as beginning to challenge this status through the Galileo system.

However, the US should not have been surprised by EU concerns over GPS in the mid-1990s; several of the EU remarks corresponded with the findings of its own review of GPS and its planned evolution. The 1994 National Defense Authorization Act called for a study to provide recommendations on the GPS program's way ahead and to ensure it continued to meet military and civilian needs, and the *Global Positioning System: Charting the Future* commission was convened, led by former US Secretary of Defense James Schlesinger. The Schlesinger commission's May 1995 summary report highlighted international acceptance of GPS as central in dissuading the development of multiple competing satellite navigation systems, thereby enabling the US to retain its leadership position in this sector. In addition, the report cautioned that the US's approach to GPS must not appear "chauvinistic or mercantilistic" by international

parties, but rather the US should foster increasing international interest in GPS by providing other nations a voice in the system's future.[1] The EU would do well to heed these same warnings in regard to Galileo, and dispel the program's air of arrogance exhibited toward GPS.

The EU highlighted Galileo as more modern than GPS, and emphasized Galileo's focus on meeting civilian and commercial, rather than GPS's military, demands. While one US argument against the Galileo program held that scheduled improvements to GPS would offset Galileo's purported technical superiority, the GPS program's susceptibility to budget-induced schedule slips made this claim implausible. In addition, the Schlesinger commission suggested that international involvement in the control of GPS and discontinuing SA might help avoid a situation of multiple competing global navigation satellite systems. However, "US reluctance to internationalize GPS governance was matched by the EU's desire to develop and maintain an independent space capability rather than continue its dependence on the US for access to space and space services."[2] Viewed in this light of competing US and EU interests, together with the realization that Europe desires autonomy in areas it considers vital to its interests, it should not be a surprise that the EU decided to proceed with its Galileo project. In the interest of promoting an improved trans-Atlantic relationship, "the US must take European initiatives in space seriously, identify the key actors, seek to understand the rationales and processes behind them, and find ways the US can benefit from European investment."[3]

Even though Europe and the US share numerous common values, both sides of the Atlantic have been in a period of strong dissonance recently; and disputes over Iraq are a symptom of larger tensions. Neither side has done a good job of managing relations, and political relations remain strained.[4] The heavy US emphasis on homeland security has complicated matters, making it more difficult for foreign scientists to get visas. Progress requires recognition of the

whole situation, including a strong acknowledgement by both sides of their real differences in interest as well as the value of their partnership, coupled with the political will in Brussels and Washington to pursue it.[5]

#2: Protect GNSS Receiver Manufacturers

As the global economy continues to grow increasingly dependent on satellite-based positioning, navigation, and timing services, so grows the market for GNSS end-user products, and US producers of GPS products stand to lose significant market share and/or gross revenue with Galileo's implementation. The US government must prevent unfair treatment of these US producers by ensuring that a fully open and competitive market remains in place for all manufacturers of GNSS receivers and by steering the EU away from implementing mandatory use requirements and market access restrictions of GNSS receivers.

If Galileo's Phase 3 operating costs prove to be too high, or its revenue streams do not produce as expected, the Galileo concessionaire will not be able to cover its costs and will likely turn to the EU for assistance. The EU could respond with additional taxpayer financing, or it could elect to subsidize the Galileo revenue stream through mandatory regulations and standards that mandate the purchase of Galileo's services. For example, the EU may assert that, since Galileo is more accurate than the current GPS civil signal, aircraft entering its airspace must use Galileo-based navigation systems in order to ensure flight safety. The US must work to ensure that any new usage standards are technologically neutral, allowing civil users to choose to use GPS, Galileo, or a combination based on their needs.

An EU decision to restrict access to or knowledge of Galileo's signals could exclude US firms from the market for Galileo satellite navigation services and equipment, and the US must ensure that all information needed for Galileo receiver production must be made equally

available to all manufacturers. Specifically, the US should work to ensure that the EU publishes all documentation for access to Galileo's Open Service, just as is done for the GPS SPS. In addition, the EU must provide equal access to the specifications for Galileo's Controlled Access services, to include openly publishing the encryption algorithms, ensuring the cryptographic key system does not exclude non-Europeans, and ensuring that any licensing arrangements and fees do not discriminate against non-European firms. The ESA did release the *Galileo Open Service Signal in Space Interface Control Document* in May 2006,[6] a positive step toward providing access to Galileo's technical information, but the US must remain vigilant and ensure that this vital information continues to flow freely, equitably, and in a timely manner to US manufacturers.

The June 2004, EU-US cooperation agreement on the use of Galileo and GPS established a forum to address these two issues. The agreement states that the US and EU will consult with each other before establishing any measures that will have the effect of mandating the use of a particular system within its territory, and that measures should not be used as a disguised restriction on or as an unnecessary obstacle to international trade.[7] To ensure that these critical aspects are upheld, the 2004 agreement established the Trade and Civil Applications working group to address non-discrimination and other trade-related issues; this group met for the first time in January 2007.[8] The US must capitalize on this working group's operational oversight to ensure that a fair and level playing field exists for all manufacturers of civil satellite-based navigation and timing end-user equipment, regardless of nationality.

#3: Compel Allied Militaries to Adopt GPS Now

Even though civilian GPS users today outnumber their military counterparts by at least 100 to one,[9] GPS is at its core a military system, providing a capability that has proven increasingly

vital to US national security over the past three decades. GPS's encrypted Precise Positioning Service (PPS) is designed to provide continuous positioning and navigation signals to the military community, even during periods of regional jamming of GPS's civilian signal due to national security crises. In this way, GPS service will only be continuously available to users with military GPS receivers. In order to preserve this military competitive advantage and the force enhancement capabilities derived from direct access to the GPS encrypted military signal, the Fiscal Year 1994 National Defense Authorization Act prohibited procurement or modification of any DOD aircraft, ship, armored vehicle, or indirect-fire weapon system not equipped with a GPS receiver after 30 September 2000 (later slipped to 30 September 2005).[10] This measure equipped US forces with GPS capability and ensured that they would remain so equipped for the foreseeable future.

The US does not typically train or fight alone, but rather in a coalition of allied forces. To ensure that all US allies enjoy continued access to critical positioning and navigation services, the US should compel these allied militaries to formally adopt the GPS PPS signal as their standard satellite-based positioning and timing service and then encourage them to fully and rapidly equip their military forces with GPS PPS-capable receivers. NATO recognized satellite navigation as a huge capability multiplier and has been heavily invested in GPS for several years.[11]

The addition of Galileo signals will provide greater precision in their military receivers; access to several positioning signals will benefit future allied forces in future missions, especially those that take place in urban areas or under heavy foliage. Failure to adopt and equip with GPS now could lead some allied militaries to choose to adopt Galileo user equipment when it becomes available, introducing risk into any operations conducted in an area where the US has

jammed Galileo in order to prevent hostile misuse of its signals; Galileo will be available to neither ally nor foe.

Presentations to explain the theory of the advantages of the PPS signal, coupled with military exercises that clearly demonstrate the survivability of PPS over SPS, will go a long way to compel allied militaries to adopt GPS. It is not necessary to disclose any specific US tactics or techniques, rather the demonstration should simply focus on what is possible. For example, constellations of UAVs over a battlespace using special antennas and signal processors to acquire the GPS signal from satellites in spite of heavy GPS jamming, and then rebroadcasting a more powerful and much closer GPS PPS signal to allied forces and weapons; this concept that was validated by the Defense Advanced Research Projects Agency (DARPA) in April 2000.[12] To further drive home the point, invite the US Air Force's 26th Space Aggressor Squadron from Schriever AFB, whose mission is "to show how a space-savvy adversary could severely hinder the air and ground campaign,"[13] to participate in the multinational military exercises; the participants will quickly appreciate the value of GPS's PPS signal.

As more and more US allies adopt the GPS PPS signal and integrate it throughout their military forces, operational and interoperability challenges introduced by Galileo's arrival will be minimized. By compelling and enabling allied militaries to adopt, equip, train, and operate with the GPS PPS signal now, the US will protect the future of the GPS PPS signal as the gold standard in positioning and navigation for combined military operations, maximizing the abilities of US and allied forces to conduct seamless operations with optimal effects during all phases of warfare.

#4: Advertise GPS Availability and Precision on Par with Galileo

Since the inception of the Galileo project, the EU and the ESA have published numerous multi-page publicity brochures touting the Galileo system and all the valuable services it will provide. Key to their brochures' argument in justifying the Galileo program is Galileo's superior availability and precision in relation to GPS. In turn, newspaper and magazine articles discussing Galileo and GPS frequently mention Galileo's advantages in these two areas, to the extent that it seems almost common knowledge in the GNSS community. However, as discussed earlier, Galileo will not be more available than GPS, and the precision of the two satellite systems will likely be a lot closer than the EU and ESA would have the readers of their brochures believe.

The EU's claims of Galileo's superiority over GPS in terms of availability and precision are somewhat understandable, as these claims are undoubtedly a significant component of the EU's ongoing campaign to attract large amounts of foreign investment. However, it is important for the US government to set the record straight, to counter these claims to the international audience whenever possible, and to promote the perception that GPS will continue to serve as the most trustworthy and reliable resource for the global community.

#5: Secure China's GNSS Cooperation

The involvement of China in the Galileo program is particularly troubling for the US. As part of a larger program of military modernization, China has sought satellite navigation services for its armed forces. While technology transfer from Europe to China and input from China into Galileo's design and operation will be limited, this cooperation will allow the Chinese to develop a more sophisticated understanding of navigational satellites. Also, China's Compass Navigation System, which is expected to become fully operational over much of China in 2008,

could use the same radio frequency as Galileo and GPS, making US attempts to jam an adversary's positioning and navigational signals much more difficult in times of crises. Ultimately, the Compass Navigation System could be used worldwide to provide precise positioning data for the Chinese military similar to information already produced by GPS to support military field commanders. Thus, China's deepening space partnership with the EU could present an immediate national security dilemma for the US, since advanced technologies shared by cooperative EU nations would almost certainly enhance China's military modernization and intelligence programs.

In order to mitigate this situation, the US and the EU should enter into multilateral discussions with China to determine how best to proceed cooperatively with GPS, Galileo, and Compass, just as the US did with the EU in 2000. The US should discuss China's current and future participation in Galileo, starting with a few questions such as "What is China's role in Galileo? What kind of access will it have to sensitive technology? What firewalls are in place to make it more difficult for China to acquire sensitive technologies through Galileo?"[14] Concurrently, the US and the EU should capitalize on the recently formed United Nations International Committee on GNSS to address compatibility and interoperability issues among the three systems. How amenable China will be to constructive and productive discussions to achieve cooperation and avoid competition between GPS, Galileo, and Compass has yet to be seen. The US and EU agreement took almost four years to conclude, and that was between two largely cooperative entities. In order to sweeten the deal and entice China to the discussion table, the US and EU could offer incentives such as a collection of GPS and Galileo lessons learned, coupled with technical assistance in developing the Compass system.

Notes

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Chapter 6

Conclusion

Once Galileo's 30-satellite constellation and network of ground stations is operational, Europe will become the third owner of a satellite radio navigation system, after the United States and Russia. Motivated by anticipated long-term industrial and economic benefits, the desire for sovereignty and security in an area it considers vital to its interests, the rectification of perceived shortfalls in GPS availability and precision, and the opportunity to strengthen EU integration and exert political autonomy from the US, the EU has been a staunch supporter of its Galileo program during the past decade. In spite of these perceived benefits, it has not been an easy road for the Galileo program, dogged by nearly four years of high-pressure negotiations with the US over broadcast frequencies as well as on-going funding and deployment concerns. In fielding the Galileo satellite constellation, the EU expects to reap economic, technological, security and political benefits when Galileo, as expected, will serve as the starting point for development of many services and applications.

In terms of the military and civilian communities' ever-increasing reliance on GPS signals, the US has become heavily invested in its GPS program during the past three decades. Therefore, the challenges that Galileo poses to vital US industrial, military, and national security interests deserve serious attention. To protect the vast industry that has developed around GPS, the US should ensure that the EU does not impose mandatory use requirements for Galileo, and

that access to the Galileo hardware market remains fair and does not discriminate against non-EU companies. Compelling US allies to formally adopt the GPS military code and equip their militaries appropriately will ensure their ability to operate continuously with the US during all levels of training and operations; this will not be the case if our allies equip with Galileo. In addition, the US must set the record straight and counter EU claims to the international audience that Galileo will be available when the US turns GPS off due to a national crisis. In all likelihood, the US will cut off both GPS and Galileo during a national crisis to prevent hostile misuse of positioning signals, and only the encrypted GPS military code will be available. And finally, the US must address China's major involvement in Galileo and the development of China's own satellite positioning and navigation system; the US should partner with the EU and enter into negotiations with China, similar to the successful US-EU discussions, and address concerns in all available multilateral venues.

There is no question that the Galileo system has much to offer and will be a great benefit to the global community, yet at the same time it poses many and varied implications. Galileo will affect the transatlantic alliance, the North Atlantic Treaty Organization, the US dominance in the defense and security of Europe, and there are serious commercial and industrial concerns as well. While understandably the US must oppose anything that would degrade the GPS's civil or military signals, or diminish the ability to deny access to positioning signals to adversaries in time of crisis, or undermine NATO cohesion, the US must continue to seek to cooperate, and not compete, with the Galileo program.

Glossary

AFB	Air Force Base
CEP	Circular Error Probable
CY	Calendar Year
DARPA	Advanced Research Projects Agency
DGPS	Differential Global Positioning System
DOD	Department of Defense
EADS	European Aeronautic Space and Defense Company
EC	European Commission
EGNOS	European Geostationary Navigation Overlay Service
ERP	Effective Radiated Power
ESA	European Space Agency
ESDP	European Security and Defense Policy
ESS	European Security Strategy
EU	European Union
GJU	Galileo Joint Undertaking
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPSOC	Global Positioning System Operations Center
HARM	High-Speed Anti-Radiation Missile
JDAM	Joint Direct Attack Munition
KAL	Korean Air Lines
NATO	North Atlantic Treaty Organization
NAVSTAR	Navigation Satellite Timing and Ranging
NAVWAR	Navigation Warfare
NSS	National Security Strategy

OEF	Operation Enduring Freedom
PDD	Presidential Decision Directive
PLGR	Precision Lightweight GPS Receiver
PPS	Precise Positioning Service
PRS	Public Regulated Service
SA	Selective Availability
SEP	Spherical Error Probable
SPS	Standard Positioning Service
US	United States

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